# A Possible Origin of Linear Depolarization Observed at Vertical incidence in Rain

A. R. Jameson
Applied Research Corporation
Landover, MD

S. L. Durden
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

March, 1995

J. Appl. Meteor.

## ABSTRACT

Recent observations by two different nadir pointing airborne radars with some linear polarization capabilities at times have detected surprisingly large linear depolarization ratios in convective tropical rain. This depolarization can be explained if the rain is considered to be a mixture of a group of apparent spheres and another group of drops that are distorted in the horizontal plane perpendicular to the direction of propagation of the incident wave. If confirmed in future observations, this suggests that at times the shapes of a significant portion of the larger raindrops are disturbed apparently because of collisions with smaller drops. Since many of the interpretations of radar polarization measurements in rain by ground-based radars presume that the raindrops shapes correspond to those of the well-known, so-called 'equilibrium' drops, the present observations may require adjustments to some radar polarization algorithms for estimating rainfall rate, for example, if the shape perturbations observed at nadir also apply to measurements along other axes as well.

## 1. Introduction

For many purposes including rainfall measurement using several recently developed radar polarization techniques, it is often assumed that raindrops are essentially quiescent, approximately oblate spheroids with their symmetry axes vertically oriented. Yet it is well known that drop size distributions evolve through the processes of coalescence, collision and drop breakup, mechanisms likely to disturb such serenity. Presently, however, it is not known whether these perturbations are of sufficient magnitude to affect significantly the quantitative interpretation of radar polarization measurements. While an exploration of this latter question is beyond the scope of this brief note, as a first step we attempt to determine here whether possible drop perturbations are at least capable of producing effects detectable in the radar signals.

There are already hints that they do at times. For example., on occasion ground-based radars detect surprisingly large vertically polarized signals backscattered from rain even when the polarization of the incident wave is horizontal. At frequencies typical of most weather radars, perfectly quiescent, horizontally aligned raindrops are incapable of producing such depolarization which requires dipole moments that are canted or tilted with respect to the polarization of the incident radar wave. Moreover, by using circular polarization radar measurements in rain McCormick and Hendry (1974) found the mean 'canting' angle (with respect to the plane of polarization) of the raindrops to be near zero but with a standard deviation of about 2°. This appears consistent with physical expectations (Beard and Jameson 1983). However, although this deviation is small it is significant because the standard deviation of the instantaneous canting angle distribution should then be between 6° to 10° if the estimate of each mean is based upon between 9 to 25 independent radar samples. Calculations show that this would be sufficient to explain most values the cross-polarization in rain observed by radars viewing along a tangent to the ground. While such canting indicates that some fraction of the raindrop distribution is indeed agitated at times, it is not clear whether the processes producing the apparent canting also change the shapes of the drops as well.

In particular suppose we observe rain using a nadir (downward) pointing radar. It is not obvious that just because some of the raindrops are perturbed that they will necessarily appear anything but spherical from the nadir perspective, Specifically, for example, the shapes associated with the fundamental mode of oscillation is one between more and less oblate (e.g., Beard et al. 1983). Because this mode is symmetric with respect to the vertical, however, it will be incapable of generating signals cross-polarized with respect to a downward propagating linearly polarized wave.

Yet at times observations from the few airborne radars capable of polarization measurements show remarkably large cross-polarization in rain *even at nadir*. For linear polarizations the magnitude of this cross-polarization is often expressed with respect to the polarization of the incident wave (the co-polarization) as the ratio of the power measured at cross-polarization to that measured at co-polarization (the linear depolarization ratio, LDR, often expressed in decibels), While at higher frequencies (> than about 30 GHz) some LDR may be due to other effects including multiple scatter, significant linear depolarization ratios approaching -2o dB have been observed in convective rain (e.g., Kumagai and Meneghini 1993) at considerably lower frequencies (around 10 GHz) for which effects such as multiple scatter are not likely to be important. While there are many potential sources for generating artifacts (e.g., side-lobes), it is unlikely that all of the observed LDR are due to artificial causes.

This conjecture is further strengthened by recent observations which also show significant values of LDR at nadir in convective rain using a completely different radar, the 13.8 GHz Jet Propulsion Laboratory (JPL) ARMAR (Area Rainfall Mapping Airborne Radar). In addition, however, the polarization measurements by the ARMAR radar are more complete than those available to Kumagai and Meneghini (1993) so that for the first time it is possible to explore the origin of these surprising LDR

Because of the nadir perspective, however, the existence of depolarization implies that there must be induced dipole moments which arc somehow lying at an angle with respect to the polarization axis of the incident wave in the horizontal plane. Consequently, unlike ground based radar observations tangent to the surface of the earth, the observed LDR can not be explained in terms of simple raindrop canting but instead requires the existence of drop distortions in the horizontal plane. It is reasonable to speculate that such distortions are the result of drop oscillations and breakup produced by drop collisions (Johnson and Beard 1984), for example. Because collisions and breakup become more frequent with increasing drop size, the distortions of raindrops are likely to be more frequent among the larger drops while many of the smaller, more numerous drops should remain largely quiescent and spherical (when viewed along the vertical). Consequently, as a first approximation it is reasonable to visualize the rain as a mixture of apparent spheres and of distorted drops rotated at all angles with respect to the polarization axis of the incident wave.

The primary purpose of this note, then, is to investigate whether such a mixture is consistent with ARMAR measurements and to see what other radar polarization measurements in conjunction with LDR can be used to decipher something about the abundance and eccentricities of the distorted drops.

## 2. Theory

The electromagnetic waves backscattered by hydrometeors generally consist of one part having the same polarization as the transmitted wave (the so-called 'co-pol' component, $E_C$) and another which is orthogonally polarized (the so-called 'cross-pol' component, $E_X$). Moreover, it is also possible to switch the transmitted waves between these two orthogonal polarizations so that, in principle, there can be two co-pol observations, $E_{C1}$ and $E_{C2}$ and the two associated cross-pol components, $E_{X1}$ and $E_{X2}$. However, because of the principle of reciprocity, it is then usually argued that $E_{X1}=E_{X2}$ so that there are actually only three independent quantities, $E_{C1}, E_{C2}$, and $E_X$. For our purposes we will also only consider a pair of orthogonal linear polarizations.

Because scatter from hydrometers is incoherent, at some point in the processing averaging is usually used to extract physically relevant mean values. Traditionally, this has been accomplished by measuring average powers ($<|E_{C1,2}|^2>$, $<|E_X|^2>$) and the magnitudes of the average cross-correlations between components ($\rho_X = |<E_X E^*_{C1,2}>|$, $\rho_L = |<E_{C1,2} E^*_{C2,1}>|$ where the asterisk denotes complex conjugation and 1,2 means either the C 1 or C2 polarization. $\rho_X$ and $\rho_L$ are also usually normalized by the square roots of the product of their respective powers.

In order to take advantage of the information contained in the different polarizations, these quantities are usually then combined so that with respect to the power measurements we have

$$\zeta = \frac{\left\langle \left|E_{C1,C2}\right|^2 \right\rangle}{\left\langle \left|E_{C2,C1}\right|^2 \right\rangle}$$

and

$$L = \frac{\left\langle \left|E_X\right|^2 \right\rangle}{\left\langle \left|E_{C1,C2}\right|^2 \right\rangle} \tag{1}$$

where the brackets denote an average and $\zeta$ is called the differential reflectivity [or $Z_{DR}$ (Seliga and Bringi 1976) often expressed in decibels], while L is the linear depolarization ratio. When viewing drops edge on at zero radar elevation angle using a ground-based radar, $\zeta$ is normally defined to be the ratio of the backscattered power at horizontal polarization to that at vertical polarization. In that case, $\zeta=1$ for spheres, and $\zeta$ is $>1$ for most raindrops. However, as raindrops become more and more canted until, in the limit, they are essentially randomly oriented, it is then well known that $\zeta \rightarrow 1$ (e.g., Jameson, 1987). From the nadir perspective this become-s critical because there is no reason to expect a preferred angular orientation of any distorted drops on the horizontal plane. Consequently, with respect to a nadir pointing radar, $\zeta$ should be close to unity and, therefore, should provide little if any information about the average shape of the drops.

On the other hand, an ensemble of distorted drops distributed with uniform probability over all rotations is not equivalent to an ensemble of spheres in two important ways. First, such an ensemble produces depolarization whereas spheres do not (at least for raindrops and at the radar frequencies normally used for meteorological radars). Second, while the correlation between the two orthogonal co-polarizations for a collection of spheres will be nearly perfect ( $\rho_L \approx 1$ ), there will be decorrelation ($\rho_L < 1$ ) for the ensemble of rotated distorted drops.

Consequently, in a manner analogous to $\zeta$ for measurements at zero elevation angle using ground-based radars, L becomes a measure of the distortion of the drops from the nadir perspective albeit a measure weighted by the co-polar backscattered power returned by the spheres which tends to reduce L. (This is also analogous to the influence of spheres on $\zeta$.) Specifically, if we assume that the scattering from the distorted drops can be adequately represented in terms of dipole moments, and if $\beta$ is the angle between, say, the long axis of the distorted drop and the polarization vector of the transmitted wave in the plane of polarization (Atlas et al 1953; Barge 1972; Jameson 1985 among others) then show that

$$\left\langle \left|E_{C1,C2}\right|^2 \right\rangle = \left\langle \cos^4(\beta)\right\rangle \sum \left|S_{oC1,C2}\right|^2 + \left\langle \sin^4(\beta)\right\rangle \sum \left|S_{oC2,C1}\right|^2 + 2\left\langle \cos^2(\beta)\sin^2(\beta)\right\rangle \mathrm{Re} \sum S_{oC1,C2} S^*_{oC2,C1}$$

$$\left\langle \left|E_x\right|^2 \right\rangle = \left\langle \cos^2(\beta)\sin^2(\beta)\right\rangle \left( \sum \left|S_{oC1,C2}\right|^2 + \sum \left|S_{oC2,C1}\right|^2 - 2\,\mathrm{Re} \sum S_{oC1,C2} S^*_{oC2,C1} \right) \qquad (2)$$

where SO denotes the ‘intrinsic’ (i.e., before rotation) backscatter matrix element and the summations are over the sampled drops. For the ensemble of distorted drops it then follows from (2) after averaging over all $\beta$ that

$$L_2 = \frac{1+\zeta_{o2} - 2\zeta_{o2}^{\frac{1}{2}}\rho_{o2}}{3\zeta_{o2} + 2\zeta_{o2}^{\frac{1}{2}} + 3} \qquad (3)$$

where the subscript 2 denotes the ensemble of distorted drops and the magnitude of the co-polar cross-correlation function $\rho_{o2}$ has been substituted for the real part of the complex correlation function (Jameson and Davé 1988). Likewise since the average magnitude of $\rho_L$ can be expressed as (Jameson and Mueller 1985; Jameson 1989)

$$\rho_L = \frac{\sum_i \left|S_{C1}\right|_i \left|S_{C2}\right|_i}{\left(\sum_i \left|S_{C1}\right|_i^2 \sum_i \left|S_{C2}\right|_i^2\right)^{\frac{1}{2}}}$$

while for dipoles

$$\begin{aligned}\left|S_{C1}\right|_i &= \cos^2(\beta_i)\left|S_{oC1}\right|_i + \sin^2(\beta_i)\left|S_{oC2}\right|_i \\ \left|S_{C2}\right|_i &= \cos^2(\beta_i)\left|S_{oC2}\right|_i + \sin^2(\beta_i)\left|S_{oC1}\right|_i\end{aligned}$$

we have after averaging over all $\beta$ and using *(2)* that

$$\rho_2 = \frac{\zeta_{o2} + 6\zeta_{o2}^{\frac{1}{2}} + 1}{3\zeta_{o2} + 2\zeta_{o2}^{\frac{1}{2}} + 3} \tag{4}$$

Consequently, both $L_2$ and $\rho_2$ produced by an ensemble of rotated distorted drops are functions of $\zeta_{o2}$. Although $L_2$ , in principle, also depends on $\rho_{o2}$, the magnitude of the 'intrinsic' co-polar cross-correlation function of the distorted drops without rotation, it will be close to unity for rain so that we may set it identically equal to one.

When these distorted and quiescent drops are then mixed, the $L_m$ and $\rho_m$ of the mixture differ, of course, from $L_2$ and $\rho_2$. Specifically, we take $L_1=0, \rho_1= 1$ and $\zeta_1= 1$ for the quiescent, 'spherical' drops, while $\zeta_{o2}= \Sigma|S_{omax}|^2 / \Sigma|S_{omin}|^2$ where the summation is over the distorted drops. Since the quiescent drops contribute to the co-polar but not the cross-polar power it follows that

$$L_m = \left(\frac{F}{1+F}\right)L_2 \tag{5}$$

where F is the ratio of the backscattered co-polar power from the distorted to that from the quiescent drops. Consequently, F may be used as a rough measure of the relative prevalence of distorted to quiescent drops, while $\zeta_{o2}$ provides a measure of the eccentricity of the distorted drops.

The effect of mixing on the magnitude of the co-pol cross-correlation function is not so obvious as it is for $L_m$. However, Jameson (1 989) gives expressions for computing such effects on p so that we have

$$\rho_m = \frac{1 + F\rho_2\zeta_{o2}^{\frac{1}{2}}}{\sqrt{\left[(1+F)(1+F\zeta_{o2})\right]}} \tag{6}$$

Consequently, using observations of the linear depolarization ratio and the magnitude of the co-polar cross-correlation function measured by a nadir pointing radar having dual-linear polarization capabilities, it should be possible to combine (5) and (6) along with (3) and (4) to solve for F and $\zeta_{o2}$ as illustrated in Fig. 1 for 0.01 $\leq F \leq 3$ and $2 \leq \zeta_{o2} \leq 30$. Note that when the measured LDR is less than about -25 dB while $\rho_m > 0.98$, reliable conclusions are unlikely since any small error in $\rho_m$ will strongly affect the estimates of F and $\zeta_{o2}$. However, in other regions of Fig. 1, more reliable estimates should be possible. In particular there arc wide range of conditions which can produce the LDR observed by Kumagai and Meneghini (1 993) and the ARMAR radar. Also note. that for constant F, as LDR increases, $\rho_m$ decreases and visa versa. Thus, it is reasonable to expect that the largest LDR will often be associated with the smallest $\rho_m$.

## 3. Some preliminary measurements

The NASA/JPL ARMAR airborne radar was conceived and assembled as a test bed for algorithm development in support of the NASA Tropical Rainfall Measuring Mission (TRMM) spaceborne radar scheduled for launch in 1997. While a more complete description of the radar may be found in Durden et al. 1994, it is sufficient to note here that it is a side-to-side scanning nadir pointing coherent radar operating at a frequency of 13.8 GHz. In addition, in its present configuration it has some dual-linear polarization capabilities, namely from pulse to pulse it can measure either the co-pol and cross-pol backscattered power or the power backscattered at alternate orthogonal co-polarizations. Consequently, it is not possible to measure LDR and $\rho_m$ concurrently at precisely the same location. Nevertheless, it is possible to switch between operating modes so that one can measure each quantity in approximately the same meteorological setting.

An inspection of preliminary measurements in convective tropical rain associated with a developing typhoon in the Western Pacific reveals several interesting features. In particular the height of the melting level often appears as a narrow band of enhanced LDR as noted by Kumagai and Meneghini (1993). Two kilometers or more below this structure, in the moist warm tropical environment it is reasonable to assume that any ice, if present, has melted (Johnson and Jameson 1982) so that the precipitation is exclusively rain. Among the interesting trends noted in these data in rain are that $\rho_m$ generally lies between 0.99 and 0.97 with an occasional observation as low as 0.95. On the other hand LDR shows a general tendency to increase with increasing reflectivity factor reaching values between -23 to -21 dB where the measured radar reflectivity factor (Z) is on the order of 45-50 dBZ. A scatter diagram of *measured* Z and LDR is shown in Fig.2. Here it should be mentioned that based upon reflection from the ocean surface, attenuation of a few to several dB is evident in many cases so that in Fig. 2 the true Z are probably a few to several dB larger than indicated. In spite of this, however, there still remains a clear trend of LDR increasing with increasing radar reflectivity factor. Correcting for attenuation is likely only to enhance this trend. In addition, there should be little if any differential attenuation between the two orthogonal linear polarizations when viewing at nadir so that the measured LDR can be assumed to represent the intrinsic LDR of the ensemble of raindrops.

In order to interpret these measurements we take $\rho_m$=0.98 and LDR=-23 dB as representative values where the measured Z=45 dBZ. This point is plotted in Fig.3, an enlargement of the relevant portion of Fig. 1. From this figure we conclude that $F\approx 1.3$ while $\zeta_{o2}\approx$ 1.7. This has several interesting implications. First, the disturbed drops appear to be rather distorted *in the horizontal* having an *average* axis ratio *r* (smallest to largest dimension) on the

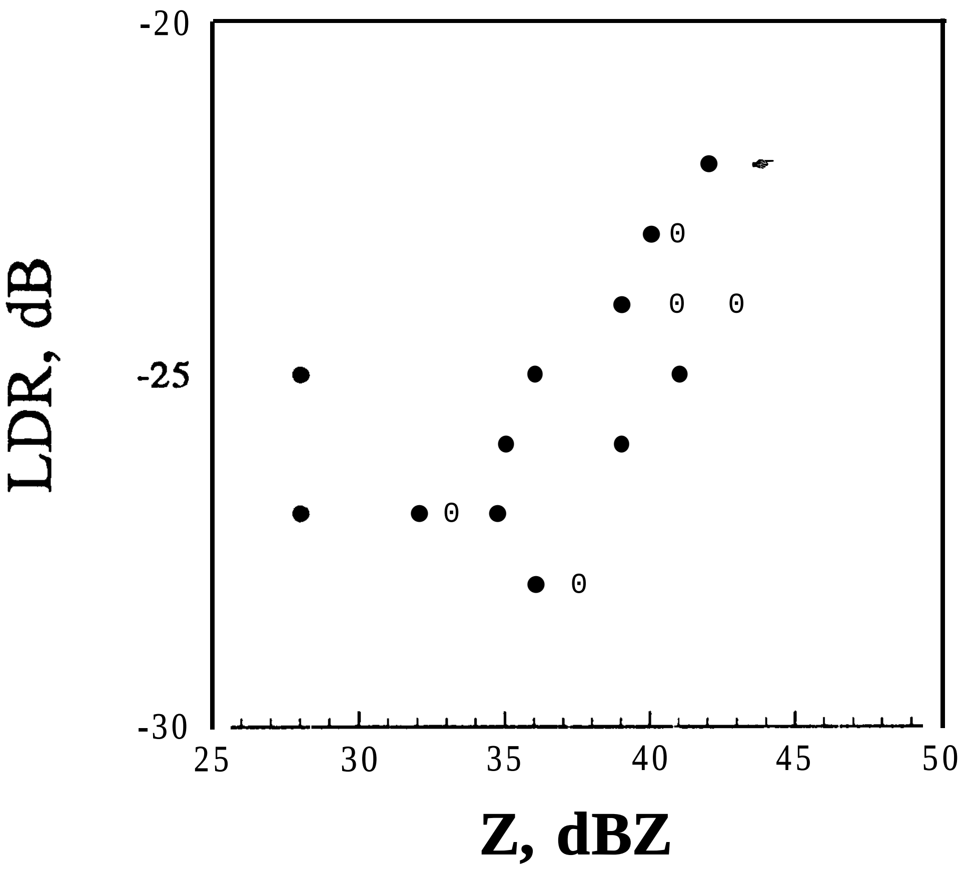


FIG 2: A plot of some pairs of LDR and the reflectivity factor measured by the ARMAR at nadir in tropical convective rain.

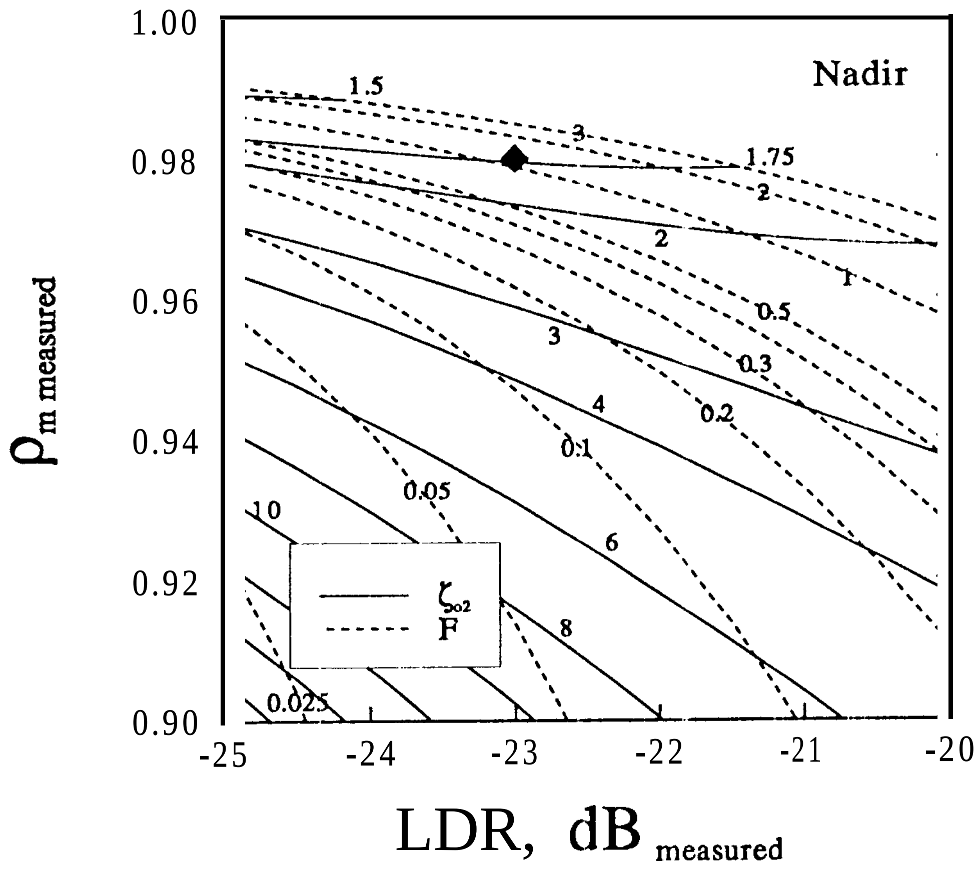


FIG.3: An enlargement of a portion of Fig. 1 showing a representative data point (diamond) corresponding to nadir observations by the ARMAR radar.

order of 0.8 [ using the relation $r=\zeta^{-3/7}$ appropriate for oblates at radar frequencies below about 10 GHz, (Jameson 1983)]. Second, F implies that just slightly greater than 56 % of the total co-polar backscattered power is produced by distorted drops.

Since smaller drops tend to be much more spherical because of the strong effect of surface tension, it seems likely that the distorted drops correspond to the larger sizes in the ensemble. Fig. 4 is a plot of the distribution of backscatter cross-section for a Sekhon and Srivastava (1971) raindrop size distribution corresponding to a radar reflectivity factor of about 45 dBZ and a rainfall rate of 35 mm h-i, fairly common in vigorous tropical showers and typhoons. Under these conditions, the shaded region in Fig.4 denotes those drops producing 56% of the power. This in turn implies that the disturbed, distorted drops are probably larger than about 2.8 to 3 mm diameter. This conclusion agrees surprisingly well with theoretical expectations of Johnson and Beard (1 984) who show that drops larger than about 3 mm diameter are precisely the ones which should be oscillating most frequently (>40% of 3 mm and up to 99% of 5 mm drops at a rainfall rate of 30 mm $h^{-1}$) and with the greatest energy (>9% of 3 mm and >50% of 5 mm drops have oscillation energies greater than 10% of their surface energies) due to collisions with the much more numerous, smaller (diameters> 300 pm) drops.

Beard et al. (1983) also suggest that at a rainfall rate of around 30 mm $h^{-1}$ departures in axis ratio corresponding to the steady-state mean oscillation energy are on the order of 0.2 to 0.4. While this magnitude appears to agree fairly well with the deviation implied by the values of $\zeta_{o2}$ above (namely 1-0.8=0.2), the amplitudes discussed in Beard et al. (1983) correspond to the fundamental mode of oscillation which produces shapes that vary between being more to being less oblate or even to becoming prolate in very extreme cases. Such oscillations are obviously

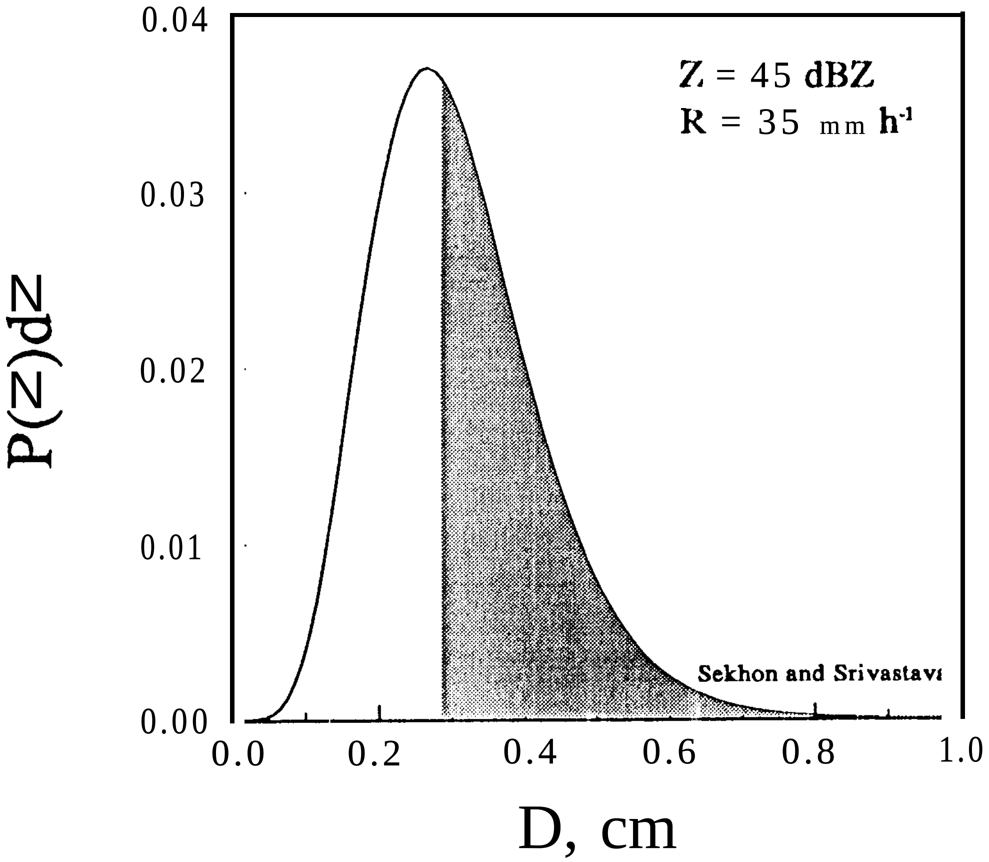


FIG. 4: A plot of the distribution of the backscattered power corresponding m a Sekhon and Srivastava (1971) raindrop size distribution in a thunderstorm as a function of drop diameter. The shaded region denotes those drop sizes producing 56% of the power and thought to correspond to the distorted drops (see text).

axisymmetric about the vertical so they are incapable of producing the observed LDR at nadir. Presumably, other modes are responsible for the horizontal distortions. Nevertheless, while the exact mode of oscillation remains unknown, theory indicates that at a rainfall rate of 35 mm $h^{-1}$ there appears to be adequate collisional energy to cause the axis ratios to deviate significantly from unity with an amplitude sufficient to produce the observed LDR This conclusion appears to be further substantiated in Fig. 2 which shows a general increase in LDR with increasing Z . Since. Z also generally increases with increasing rainfall rate, the observed increase in LDR, indicative of greater average drop distortion, is probably more than a coincidence. When the rainfall rate is too small, collisions are incapable of inducing and sustaining profound oscillations in a significant fraction of the larger drops, whereas as the rainfall rate increases, more and more drops can oscillate with increasing energies and amplitudes.

## 4. Summary and implications

A simple model of rain as a combination of a group of quiescent, apparently spherical (from the nadir perspective) drops and another group of distorted drops rotated at all angles with respect to the axis of a linearly polarized, downward transmitted wave appears sufficient to explain the origin and magnitude of $\rho_m$ and LDR observed in convective tropical rain at nadir by the ARMAR radar and also reported by Kumagai and Meneghini (1993), As a result there appears to be good qualitative and general quantitative agreement with the idea that collisions between large and smaller drops produce and sustain drop oscillations and distortions over a significant fraction of the larger drops with a magnitude sufficient to affect radar scattering.

If true, this conclusion has some potentially important implications. For one even the shapes of the raindrops observed by ground-based radars may be affected by oscillations.

Consequently, some (*but not ail)* algorithms for estimating rainfall based on polarization measurements may need some revision if it is found that the shapes of some of the raindrops depend upon the rainfall rate itself, for example. Another implication may be that enhanced backscatter at cross-polarization measured using spaceborne radar observations near nadir may be a useful qualitative if not quantitative indicator of rainfall intensity at least below the freezing level. This possibility is currently under investigation by the authors using data collected by the SIR-C/X-SAR radars as part of the NASA Shuttle Radar Laboratory experiments in 1994.

Clearly, these statements are somewhat speculative and these results need further substantiation. One obvious improvement, for example, would be the addition of a second receiver channel to the ARMAR radar so that both LDR and $\rho_m$ could be measured simultaneously. However, even then the establishment of a solid link between radar observations and drop microphysics requires not only more complete observational data but also improved understanding of the physics of the modes and amplitudes of raindrop oscillations through theoretical and laboratory research.

*Acknowledgements:* A.R. Jameson was supported for this research by grants from NASA (NAS5-32780) and JPL (JPL-958437). Participation by Dr. Steve Durden was supported by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

## REFERENCES


Atlas, D., M. Kerker, and R Wexler, 1953: Scattering and attenuation by non-spherical atmospheric particles. *J. Atmos. Terrest. Phys.*, 3, 108-119.

Barge, B. L., 1972: Hail detection with a polarization diversity radar. Stormy Weather Group Sci. Rep. MW-71, McGill University, 80 pp.

Beard, K. V., and A. R Jameson, 1983: Raindrop canting. *J. Atmos. Sci.*, 40, 455-462.

—, D. B. Johnson, and A. R Jameson, 1983: Collisional forcing of raindrop oscillation. *J. Atmos. Sci.*, 40, 455-462.

Durden, S. L., E. Im, F.K. Li, W. Ricketts, A. Tanner, and W. Wilson, 1994: ARMAR: An airborne rain-mapping radar. *J. Atmos. Oceanic Technol.*, **11**, 727-737.

Jameson, A. R, 1989: The interpretation and meteorological application of radar backscatter amplitude ratios at linear polarizations. *J. Atmos. Oceanic Technol.*, **6, 908-919.**

—, **1987:** Relations among linear and circular polarization parameters measured in canted hydrometers. *J. Atmos. Oceanic Technol., 4, 634-645.*

—, 1985: On deducing the microphysical character of precipitation from multiple-parameter radar polarization measurements. *J. Clim. Appl. Meteor., 24,* 1037-1047.

—, 1983: Microphysical interpretation of multiparameter radar measurements in rain. Part I: Interpretation of polarization measurements and estimation of raindrop shapes. *J. Atmos. Sci., 40,* 1792-1802.

—, and J, H. Davé, 1988: An interpretation of circular polarization measurements affected by propagation differential phase shift. *J. Atmos. Oceanic Technol.*, 5, **405-415.**

—, and E. A. Mueller, 1985: Estimation of differential phase shift from sequential orthogonal linear polarization radar measurements. *J. Atmos. Oceanic Technol., 2,* 133-137.

Johnson, D. B., and K.V. Beard, 1984: oscillation energies of colliding raindrops. *J. Atmos. Sci.,* 41, 1235-1241.

—, and A.R. Jameson, 1982: On the melting of graupel and frozen raindrops. Preprints, *Conf.* on *Cloud Physics* (Chicago), Amer. Meteor. Sot., Boston, 384-387.

Kumagai, H., and R Meneghini, 1993: Preliminary results from multiparameter airborne rain radar measurements in the Western Pacific. *J. Appl. Meteor., 32, 431-440.*

McCormick, G. C., and A. Hendry, 1974: Polarization properties of transmission through precipitation over a communication link. *J. Rech. Atmos.*, **8**, 175-187.

Sekhon, RS., and R.C. Srivastava, 1971: Doppler radar observations of drop-size distributions in a thunderstorm. *J. Atmos. Sci.*, 28, 983-994.

Seliga, T. A., and V. N. Bringi, 1976: Potential use of radar differential reflectivity measurements at orthogonal polarizations for measuring precipitant ion. *J. Appl. Meteor.*, **15, 69-76.**